



DC for Data Centers Workshop

Hosted by Intel Corp
Santa Clara, CA
July 12th, 2007

Workshop Overview:

Over 80 attendees representing over 40 companies from all facets of the data center industry

Voltage Levels: Rationales for different voltage levels were presented from industry leaders. There were differing opinions, but most of the discussions favored an eventual voltage between 350 and 400V. The demonstration team including Sun, Intel and others were strong proponents of a 380V solution for the future of DC data centers. However, there are also solutions available today at 550/575V that distribute 48VDC to the load. Many consider this a viable interim solution while the development of 380VDC continues.

Power & Distribution: The panel identified solutions and working examples of current DC power distribution in the telecom industry and lighting applications. DC power has additional benefits in connecting renewable energy applications like solar and fuel cells.

Safety and Grounding Issues: A list of key safety issues were identified with 5 being identified as highest priority for further study:

- Study existing 380VDC circuit protection solutions, leakage currents and shock hazards.
- UL rated 380VDC connection devices
- Power distribution equipment within the rack
- Training and certification of personnel working inside the racks
- Training and certification of personnel installing building power distribution

Contacts/Connectors and Other Hardware: Existing connector designs, standards and efforts were presented and identified by the group. Next steps for this topic included:

- Develop a process for standardization of 380VDC connectors
- Further evaluation of hold up time for PSUs
- Research DC breakers currently available from Europe

Coordination Discussion

Panel members and the group discussed how to advance the issue of energy efficiency and DC distribution. Key takeaways included:

- Implementing a "real world" pilot project with real products is a high priority. Stakeholders agreed to take action in finding options for the project site and assemble product map/design for the pilot project
- The need to further develop a cost-benefit analysis and value proposition for a DC data center architecture
- Need to tap into current sustainability momentum in the marketplace
- Challenge of "economic inertia" can be helped in areas that have utility incentive support (e.g. PG&E and Duke Energy)



Workshop Notes:

Background, Workshop/Symposium Objective

Bill Tschudi, LBL

- Power conversion (power supply efficiency, UPS efficiency, DC power architecture to limit conversions, 10 – 15% energy savings) idea initiated from RMI Charrette.
- Loose ends from demonstration:
 - 1) Voltage standard
 - 2) Standardizing connectors
 - 3) Pilot project
- Green Grid has agreed to put DC power on their technical review agenda
- Power supply needs to go through UL certification process
- A suggestion was made that other power delivery alternatives be considered as part of the workshop and looking forward
- The Green Grid is working on and considering the alternate solutions
- Any solutions that improve end to end efficiency are desirable

Voltage Panel Presentations and Discussion

Review and discuss rationale for voltage level, examine other efforts (EU), and coordinate or incorporate changes. The goal of this discussion is to reach consensus and then publicize this to a broad audience of stakeholders. Also consider the additional issues below:

- Targets for load capacity with a rationale
- Power Supply Options: New power supply designs and options in a DC system
- Equipment Certification: Transition “Beta” equipment to full UL-listing status for commercial availability

Annabelle Pratt, Intel

- DC UPS straight thru to server power supply unit (PSU)
- What is the best voltage to distribute to server?
 - o 380V DC and 350V DC
- PSUs not available commercially but can be easily derived from AC products

Mike Bushue, Sun

- Sun in DC demonstration was able to convert AC power supplies to DC from their existing server lines by replacing a few components and making minor adjustments
- Operating in DC world means that utility is not providing fault current. This needs to be provided through a rectifier. Fault current is defined by upstream power source
- Marketplace drivers for technology in a server power supply: cost, efficiency, density, standardization, volumes
- Mitsubishi and APC UPSs used in previous DC demonstration
- Converting a PSU from AC to DC use can provide a 1 – 3% efficiency gain
- Power per compute has been improved by 10 to 30 times in past 5 yrs, but industry wants 30 to 50 times
- If you go above 380Vdc (directly into the server) the DC/DC converter topology has to change and different silicon devices (typically MOSFETs) with a higher voltage rating would be required
- UL60950 covers voltage levels and spacing. If you go above 420Vdc the spacing requirements are different

Stefan Lidstrom, Net Power Labs, Sweden

- Have DC based UPS systems and has been testing for 18 months



- Utilized 350Vdc
- If you go above 450Vdc you need a whole new set of components
- Not using 380Vdc because there are standard power supplies available rated for 370V DC input in Europe
- AC/DC converter is not isolated. This makes the transformer large but is tradeoff for higher efficiency curves and reliability
- 350V DC gives lower component stress compared to 240VAC
- 350V DC is recommendation for servers and other equipment (lighting, cooling, etc.)
- System has demonstrated up to 96% efficiency (between 30 and 85% load). Claim that no other type of system is as efficient. Some thought there are other systems as efficient
- Why 350V DC? Just as long as it's below 400, BUT 350 will allow for easier transition because there are many more power supplies and other equipment available for up to 370V DC
- Need larger ranges of voltage to utilize amounts of stored energy in a DC system (audience comment)

Keiichi Hirose, NTT Facilities, Japan

- Sendai Project
- Uses 300V DC from PV 50 kW PV panels
- DC power used for servers, fans and lighting.
- 300V DC chosen for project because of low AC voltage and DC grounding ordinances
- In the future, willing to consider voltages up to 400V DC and working to change ordinances to support this

Rudy Kraus, Validus DC Systems

- Takes into account cost of wiring (copper is expensive)
- Validus systems tested to UL6950
- Recommends 550 - 575V line (gets the most out of lead, batteries float at 540V)
- Used batteries and flywheels in system
- AC to DC converters not isolated due to efficiency concerns, used in conjunction with a 60Hz transformer which provides isolation
- System uses 48V PSUs (low voltage)
- 48V DC power supplies are more efficient, especially if using a single PSU.
- DC variable motors exist and will be more readily available in the near future for DC architecture (600 VDC cooling design)
- 88% efficiency from end to end
- Experience from customers is that they feel more comfortable with 54V on the "floor" and at the rack/cabinet level due to safety concerns and perceptions.
- Advantage is that servers are available at 48V DC today

Bharat Shaw, PSMA Representative and Emerson Network Power

- Presented collection of comments from PSMA members (see presentation slide details)

DC Voltage Panel Q&A (Moderated by Mike Bushue)

- Q: It would be good to see benefits of using 550V/575V to "rack row" system vs. 380V system UPS to server straight through system? A: Uses lead better, (Validus)
- 240AC is just as lethal as DC levels (Stefan Lidstrom)
- Transfer to DC architecture could be a two step process (Bill T., LBL), but wiring types would need to be sized for largest current (audience)
- Additional DC/DC conversion step has to be oversized in order to blow fuses (Stefan Lidstrom)
- 380 – 400V is a sweet spot from PSU efficiency perspective (Delta rep.)
- Cost-effectiveness study and decision matrix was recommended



- Protecting people from 380 or 575V makes no difference because both are lethal (audience member with yrs of experience at UL)
- How do you calculate ARC flash when using over 50V?
- Sun and HP does not want to give up last isolation boundary (ability to have redundancy, service, maintenance, etc.), so not in favor of bringing facility 48V DC power directly to backplane
- Intel prefers 380V system in the future. Sees 550/575V DC as a system that can be implemented today, e.g. Validus system (Annabelle, Intel)
- Improve efficiency and reliability by removing conversions steps. 96% percent efficiency in server room where cooling is an issue (Stefan Lidstrom)
- Will start discussion with Japanese industry to increase voltage level above 300V and (Hiroshi, NTT)
- Sun is looking to make servers as efficient as possible. Proponent of 380V solution because it is what's available in PSUs today. (Mike B.)
- There is not much difference between 350 and 400V. - so all solutions in this range are similar

Power/Distribution Panel Presentations

Review and discuss issues related to power distribution, and identify/recommend solutions as well as working examples. The goal of this discussion is to examine areas not previously covered by the Final Report.

- Power distribution to receptacles: Bus bar versus wires
- Voltage and distance issues
- Sparking and transients caused by hot disconnect of receptacle and plug
- Stranded versus solid conductors
- Wire metallurgy
- Where best to perform the primary rectification?

Paul Savage, Nextek

- Started using DC distribution system for lighting
- Worked with Phillips to get 380V acceptable to use with existing standards
- Additional efficiency gains from using DC power for other equipment (lighting, cooling, etc)
- Worked with Carrier and Trane to deliver DC to HVAC equipment
- DC networks are proliferating

Alex McEachern, Power Standards Lab

- DC Disturbances will happen and need to be planned for
- Disturbances can alter voltage levels and have a ripple effect. PSUs need to be designed to handle a range of unplanned voltage levels
- Recommendations:
 - 1) Gathering data on DC disturbances at equipment terminals
 - 2) Need to report findings back to designers of DC loads
- 48V disturbances are there but relatively small.
- Higher voltage dramatically raises impedance and potential for disturbances

William Bush, Panduit

- Showed Telco examples (see workshop presentation slides)
- Recommended having awareness of terminology within different industries (high vs. low voltage)

**Mick McDaniel, Satcon**

- Focused on data centers and renewable energy
- Q: Where to perform the primary rectification? A: It depends
- From rectifier perspective the voltage level/standard isn't a major concern
- PV inverter was used in Sun demonstration as a "DC rectifier". Example of possible form factor for future DC systems
- Predicts an installation of a DC data center in 18 to 24 months
- Energy efficiency is the lowest hanging fruit for customers. Make energy efficiency cool by saving MONEY

Dennis Petkovsek, Emerson Network Power

- Where to locate primary rectification? A: closer to server to minimize DC loop resistance, inductance
- 480VAC, 48VDC distribution is well understood
- Ease of expansion, modularity and hot plugging is important
- Grounded system is preferred
- 380V is under study at several divisions
- Standardization needs to happen for HVDC

Power/Distribution Discussion

- Other industries utilizing DC power like military in aircraft. DC power could be a preferred for plug-in vehicles. It is also used at GM plants.
- Savings on energy bill will drive the consumer market

Safety & Grounding Issues

This discussion will review safety information and prioritize issues for discussion, recommend solutions.

- Safety and grounding
- Does the plug / receptacle serve as an emergency power off?
- Hold up time / circuit breaker response time
- Current capacity of receptacle, connector, appliance wire
- Distribution to the receptacle?
- Filtering / FCC conducted / radiated emissions considerations

Safety Issues Identified

- Standards today
- Training
- Components (Connection devices)
- ARC Flash
- NEC
- IEEE (ARC Flash Standards Committee)
- OSHA concerns
- Maintenance
- Models
- Compatibility
- Leakage currents (UL60950 is a good reference)
- Under floor power distribution
- Warnings/labels



William Bush, Panduit Corp.

- Terminology is important when considering grounding issues.
- "Grounding and bonding is a science, but an art of application"
- Greater than 160V and lower than 600V there is not much historical knowledge
- Which lead is the Return path (plus vs. minus)? Historically the positive has been grounded
- Grounding the return lead (source vs. load)?
- Where are we at today? Recommendation is to ground at source and not the load
- Grounding of alternate power source (batteries or something else?)
- Where does the "higher" voltage DC get placed? Recommended to be in a restricted access area.
- ANSI Standard 607A (Standard for grounding in commercial buildings)
- Telecommunications Ground Bar (TGB) and Telecommunications Main Ground Bar (TMGB)

Doug Dorr, EPRI

- Lighting and surge protection
- Safety
 - o Circuit protection issues
 - o UL listings
 - o Personnel training
- Insulation levels are already up to 600V rated
- Special labels and warnings?
- Anything under 50V AC and 60V DC won't cause death (various standards)
- IEEE (U.S.) design guidelines will be useful in effort
- EPRI working with IEEE to create DC distribution document/guidelines (contact Doug Dorr to participate)

Safety Issues Discussion

Top 5 Safety Issues:

- Selecting and locating suitable circuit protection. Leakage currents and shock hazards.
- Connection devices
 - o Power distribution equipment within the rack
- Training and certification of personnel working inside the racks
- Training and certification of personnel installing building power distribution

Contacts/Connectors and Other Hardware Panel Presentations

Review existing connector designs and efforts, outstanding issues (below) and recommend a standard form. The proposed standard would be presented to EU and US standards bodies (IEEE? Others?)

- DC Connectors: Standardization process for DC connectors.
- Receptacle and plug physical design considerations
- Common impedance issues?
- Should the receptacle disable the power when there is no plug plugged in?
- Should the connector incorporate physical retention / locking?
- Insertion and withdrawal force
- Contact metallurgy and mechanicals
- Contact resistance/reliability and wear

Brian Davies, Anderson Power Products

- Makes DC power connectors in Telco, forklift, and data center applications. Largest manufacturer of DC power connectors



- High voltage DC batteries being used today
- Requirements for 400 DC connectors
 - o Has to have touch safe connectors
 - o IP20 Standards in Europe and UL 1977 in U.S.
 - o Hot swapping?
 - o Size compatibility with IEC 320 inlets
- APP connector (used in Intel demonstration, in APC and Rackable's applications)
 - o Hot pluggable
 - o Tyco makes similar connector product
 - o Flat geometry of connector helps survive ARcing
- Only company that has tested for hot plugging.
- Enabling circuit used in higher amperages

David Geary, Direct Power Technologies

- What standards exist today for DC connectors? (see slide)
- Examples from other industries (see slide)
- Standardization process for DC connectors?
- Nominal voltage rating of a system will drive connectors

Contacts/Connectors Discussion

- A next step is to look at other available DC breakers from Europe
- Hold up time for PSUs needs further evaluation. Could need more than typical AC system? Compare to Telco systems and ANSI standard?

Coordination Panel Presentation

Coordination with various programs and representatives to advance the issue of energy efficiency and DC distribution.

- Advancing the topic at Green Grid, CENELEC, etc
- On-site implementation: Recruit partners for on-site DC architecture delivery option
- Cost Comparison: Perform a cost model comparison between typical high reliability AC systems vs. a DC system topology, as well as collect data for TCO analysis.
- Update Efficiency Data: Perform more efficiency data measurements within a real life data center environment.
- Education and Outreach: Continue to publicize the potential energy savings for a DC system and obtain involvement of code and standard development organizations to begin the development of universal standards for higher-voltage (350V up to 500V DC) systems for data centers.
- PG&E Update: rebate programs and utility coalition to capture energy efficiency opportunities in data centers

John Richard, Morrison Hershfield

- What we've been hearing in the marketplace
 - o DC is not ready for primetime
 - o First cost is too expensive
 - o TCO has not been established
- PG&E and Duke Energy want to give incentives for data center efficiency
- IT managers do not want to hear a new power distribution solution that would change their IT strategy
- Need to tap into sustainability momentum
- Develop credible TCO calculator



Brian Fortenbery, EPRI

- Cost-benefit analysis to develop and to post on LBL website
- Make sure power quality is considered for DC (Important for electric utilities)
- Availability is better measure than Reliability
- Probabilistic Risk Assessment (see slide)
- Data centers will always use efficiency to increase capacity not to decrease energy

Coordination Discussion

- Economic inertia challenge can be helped in areas that have utility incentive support
- CIOs think in compute cycles as well as energy savings
- BASF has a great model for TCO
- Pilot project with real products was agreed to be a high priority. Next steps:
 - o Action item to find a site
 - o Put together what pilot system and product map will look like